

CHANNEL PROTECTION AGAINST HIGH VELOCITY FLOWS

CIVIL WORKS INVESTIGATION 452-G



NEW ENGLAND DIVISION, CORPS OF ENGINEERS, U. S. ARMY

BOSTON, MASSACHUSETTS

AUGUST 1950

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1. Authority. - This report is submitted under authority contained in multiple letter from the Office of the Chief of Engineers, dated 24 June 1949, subject: "Civil Works Investigation", file number ENGWE 812, in which Investigation No. 452-G, Channel Protection Against High Velocity Flows, was assigned to the New England Division.

2. Scope. - A physical inspection was made of all types of channel and slope protection constructed by the Corps of Engineers in the New England Division. Hydraulic analyses were made to determine the maximum design and experienced velocities. Data on those types which have experienced velocities in excess of 6 feet per second, together with photographs and sketches showing details of construction, are included in this report.

3. Description of Projects. - Velocities in excess of six feet per second have been experienced at five local protection projects constructed by the Corps of Engineers in the New England Division. The locations of these projects are shown on plate 1. A brief description of each project is given below.

a. Fitchburg, Mass. - This project consists of improvement of approximately five miles of channel in the North Nashua River in the city of Fitchburg, Mass. The improvement included channel deepening, widening and realignment, removal of existing dams, dike construction, riprapping, protection of structure foundations, construction of re-

taining walls, reconstruction of a railroad trestle and construction of a diversion conduit. The main channel has grades up to 2.00%. A general plan of the improvement is shown on plate 2.

The project, completed in January 1938, is designed for flood flows up to 9,000 c.f.s. and velocities up to 18 feet per second in isolated locations. In September 1938, the newly-completed channel was subjected to a flood flow of approximately 8,000 c.f.s. with estimated velocities up to 18 feet per second being experienced.

b. Northampton, Mass. - This project consists of earth dikes, concrete flood walls, a pumping station and a diversion canal approximately two miles long. The upper 2800-foot length of the diversion canal is on a 0.22% grade and has riprapped bottom and sides. The riprapped portion terminates at a concrete drop structure and stilling basin, from which point the remaining canal is level with no bottom or slope protection. A general plan of this project is shown on plate 3.

The canal, completed in 1940, is designed for flood flows up to 30,000 c.f.s. and velocities up to 13 feet per second in the riprapped section. The maximum flow to which the canal has been subjected to date was 3,100 c.f.s. in April 1945, with estimated velocities up to 8 feet per second being experienced at that time.

c. Holyoke, Mass. - This project consists of earth dikes, concrete flood walls and pumping stations along the Connecticut River at Holyoke, Mass. A general plan of the project is shown on plate 4.

The project, completed in 1948, is designed for flood flows up to 230,000 c.f.s. and velocities up to 9 feet per second in the

vicinity of the Boston and Maine Railroad bridge. The maximum flow to which these slopes have been subjected to date was 140,000 c.f.s. in December 1948, with estimated velocities up to 8 feet per second being experienced at that time.

d. West Springfield, Mass. - This project consists of earth dikes, concrete flood walls and pumping stations along the Connecticut and Westfield Rivers in West Springfield, Mass. A general plan of the project is shown on plate 5.

The project, essentially completed in 1940, is designed for flood flows up to 250,000 c.f.s. on the Connecticut River and 60,700 c.f.s. on the Westfield, with maximum velocities up to 10 feet per second on the Westfield River above the Agawam Bridge. The maximum flow to which this protection has been subjected to date was 140,000 c.f.s. on the Connecticut River and 32,200 c.f.s. on the Westfield River in December 1948. Maximum estimated velocities above the Agawam Bridge were 8 feet per second at that time.

e. Lowell, Mass. - This project consists of earth dikes, concrete flood walls and pumping stations along the Merrimack River and Beaver Brook in Lowell, Mass. A general plan of the project is shown on plate 6.

The project, completed in 1942, is designed for flood flows up to 173,000 c.f.s. on the Merrimack River, with maximum velocities up to 15 feet per second along the Lakeview Avenue Section. The maximum flow to which this protection has been subjected to date was

48,000 c.f.s. in June 1944, with estimated velocities up to 10 feet per second being experienced at that time.

4. Types of Protection. - Details and photographs of the various types of channel and slope protection which have been subjected to velocities in excess of 6 feet per second, together with pertinent data thereon, are shown on figures 1 through 12. The locations at which these various types have been constructed are shown on plates 2 through 6 described above. Types of protection and locations which have been subjected to velocities less than six feet per second are not shown.

5. Hydraulic Analyses. - Velocities of flow were determined by dividing the maximum design or experienced flood discharge by the total effective cross-sectional area. This computation results in a mean velocity for the section. True bank velocities, affecting stability of protected areas, are indeterminable and are dependent on (a) bank friction, (b) depth of flow or hydraulic radius near the bank areas, and (c) alignment of the river channel, -- that is, whether the protection is on the inside or outside of channel curvatures. In most cases, it is expected that the bank velocities will be less than the mean velocities shown, but no attempt has been made to evaluate the cross-sectional velocity distribution.

Where the protection extends up a tributary, as at West Springfield, protection is provided principally against backwater from the main river. In such cases, maximum velocities in the tributary occur with minimum stages on the main river.

No attempt has been made to evaluate design and experienced velocities in riprapped tailrace and pumping station outlets which are designed to prevent scour from discharge during low river stages and erosion due to eddy action during high river stages.

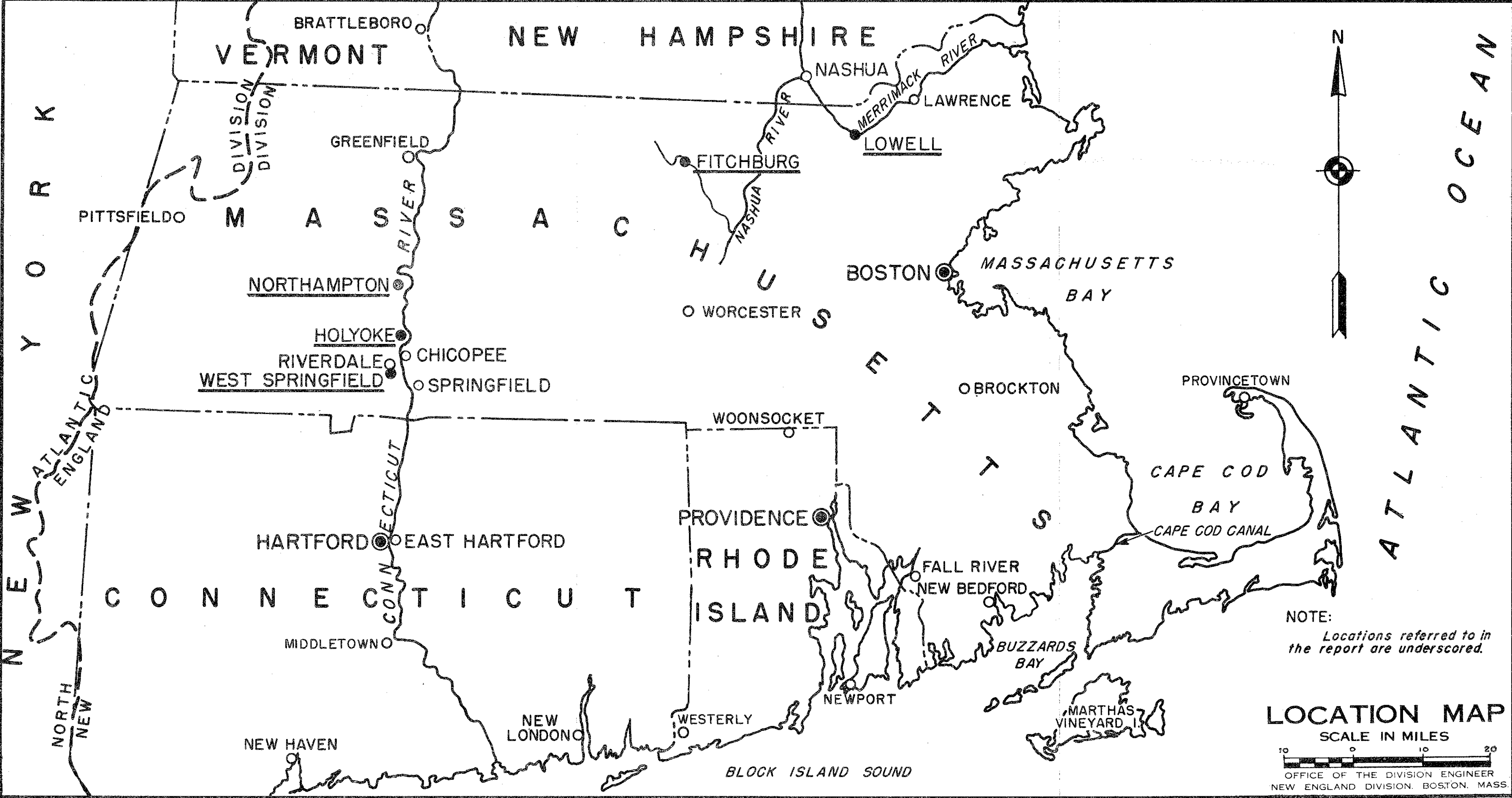
6. Discussion. - In general, all types of protection constructed by the Corps of Engineers in the New England Division have withstood the velocities to which they have been subjected to date. Where properly maintained by the local agencies charged with maintenance, the riprapped slopes, as well as slopes protected by gravel or topsoil and grass, have remained in excellent condition. The only type of protection which has suffered any appreciable damage is some of the grouted riprap (Type "C") in the Fitchburg Channel Improvement project. Photographs of damaged portions of this type of protection are shown on figures 13 and 14. In these instances, damage is believed to have been caused by progressive erosion or scour of the material underlying the riprap.

7. Conclusions. - Based on experience acquired from projects constructed over a decade ago which have withstood substantial velocities successfully, it would appear that some portions were over-protected. Hand-placed riprap was used extensively during the period of the W.P.A., E.R.A., etc., when emphasis was placed on utilization of the maximum possible amount of manpower and the minimum amount of machinery and materials. Experience with less costly types of protection indicates that the current high cost of hand-placed riprap is not justifiable except under severe erosion conditions. Where conditions are not par-

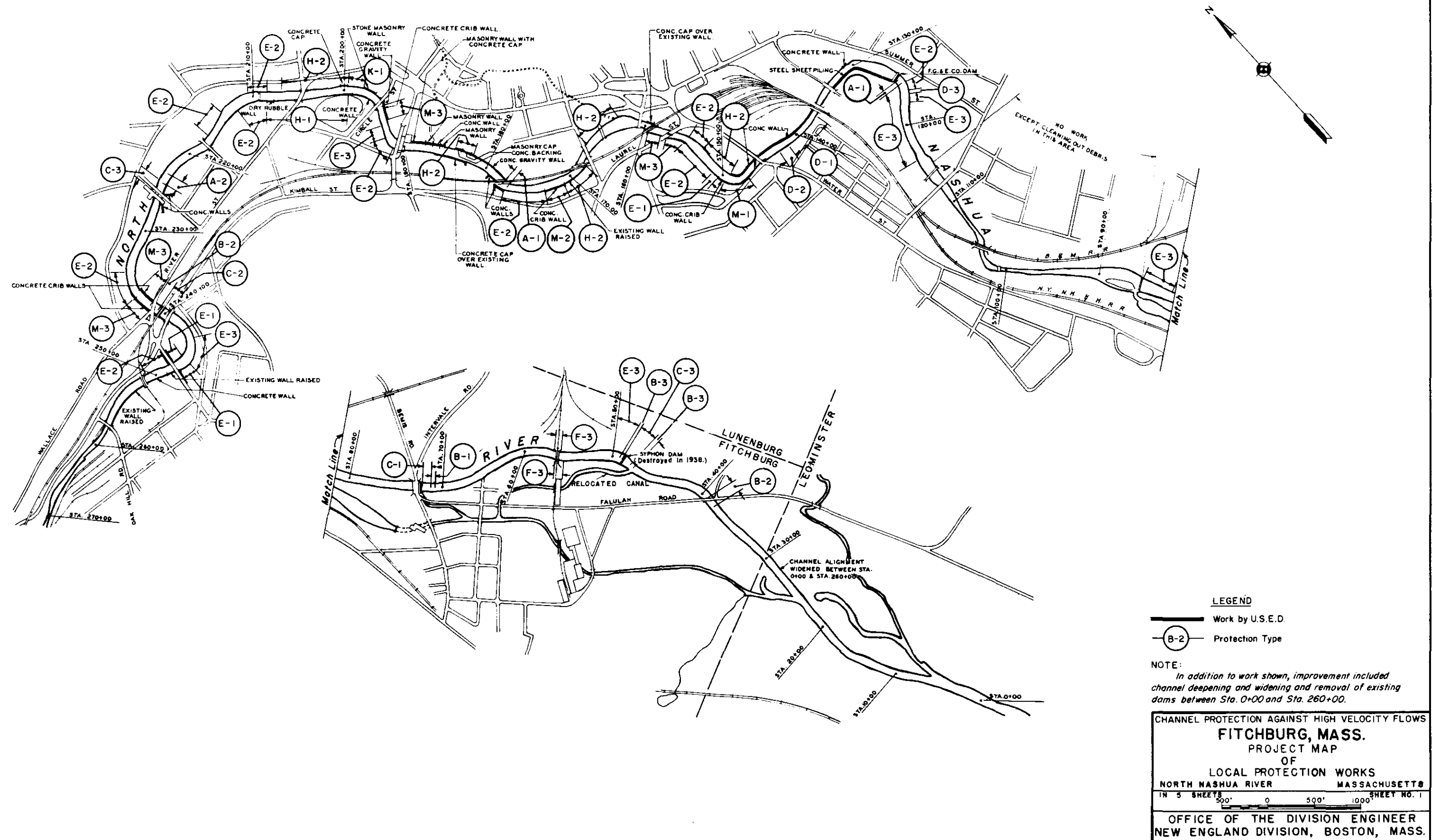
ticularly severe, less costly types of protection are presently being employed by this office, such as dumped rock or, in the case of only moderate velocities, gravel blanket or topsoil and seeded slopes. However, these forms of protection have not been subjected to high velocities to date. With respect to the last-named type, it was the practice of this office to specify that such slopes should be topsoiled, spot-sodded and seeded, the sods being 4" to 6" square and placed 18" to 24" on centers. Spot sodding proved to be expensive and of dubious value and consequently has been omitted from subsequent specifications. Grouted riprap has likewise been omitted from recent plans where there was any danger of its being undercut.

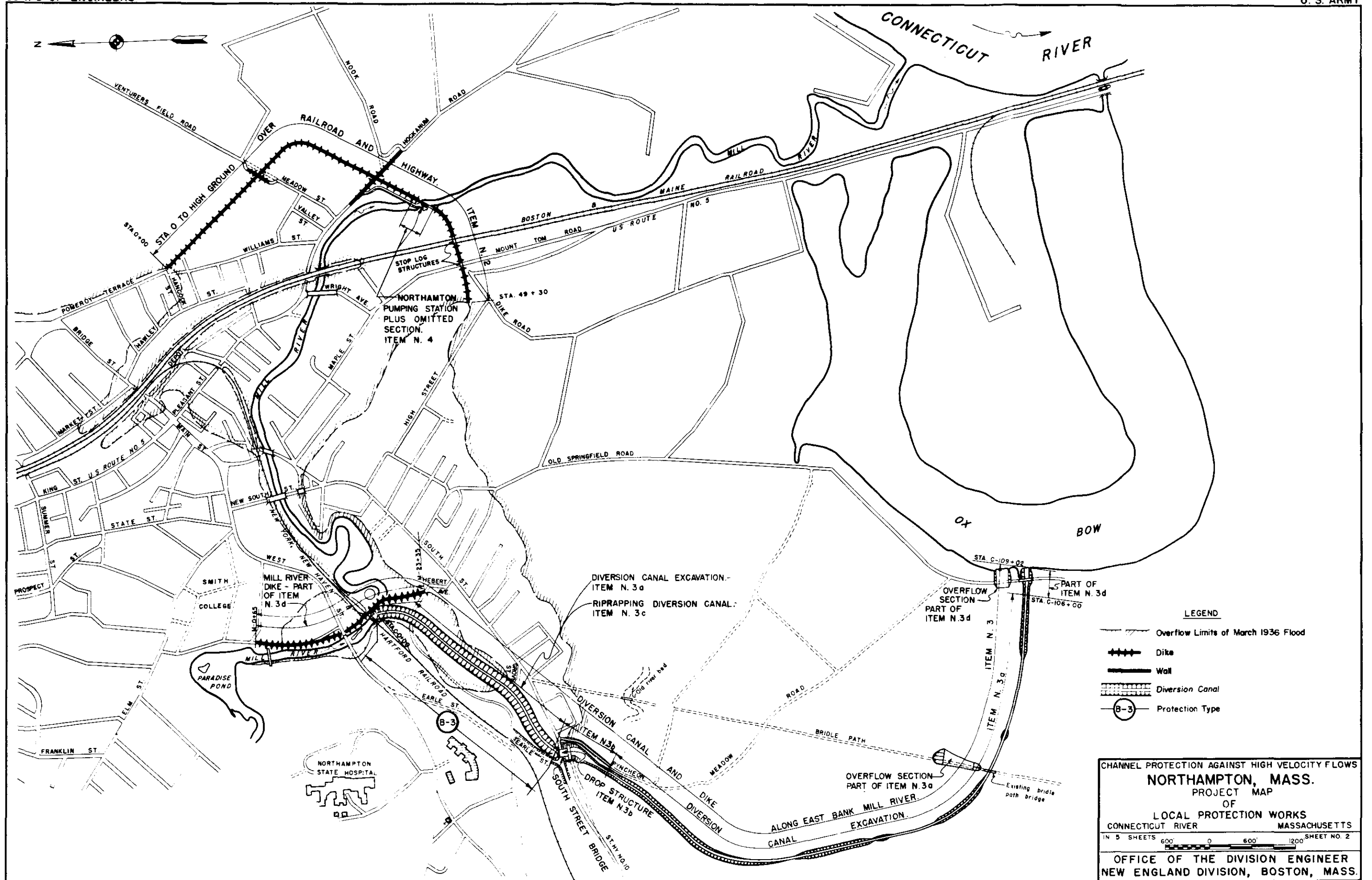
H. J. WOODBURY
Colonel, Corps of Engineers
Division Engineer

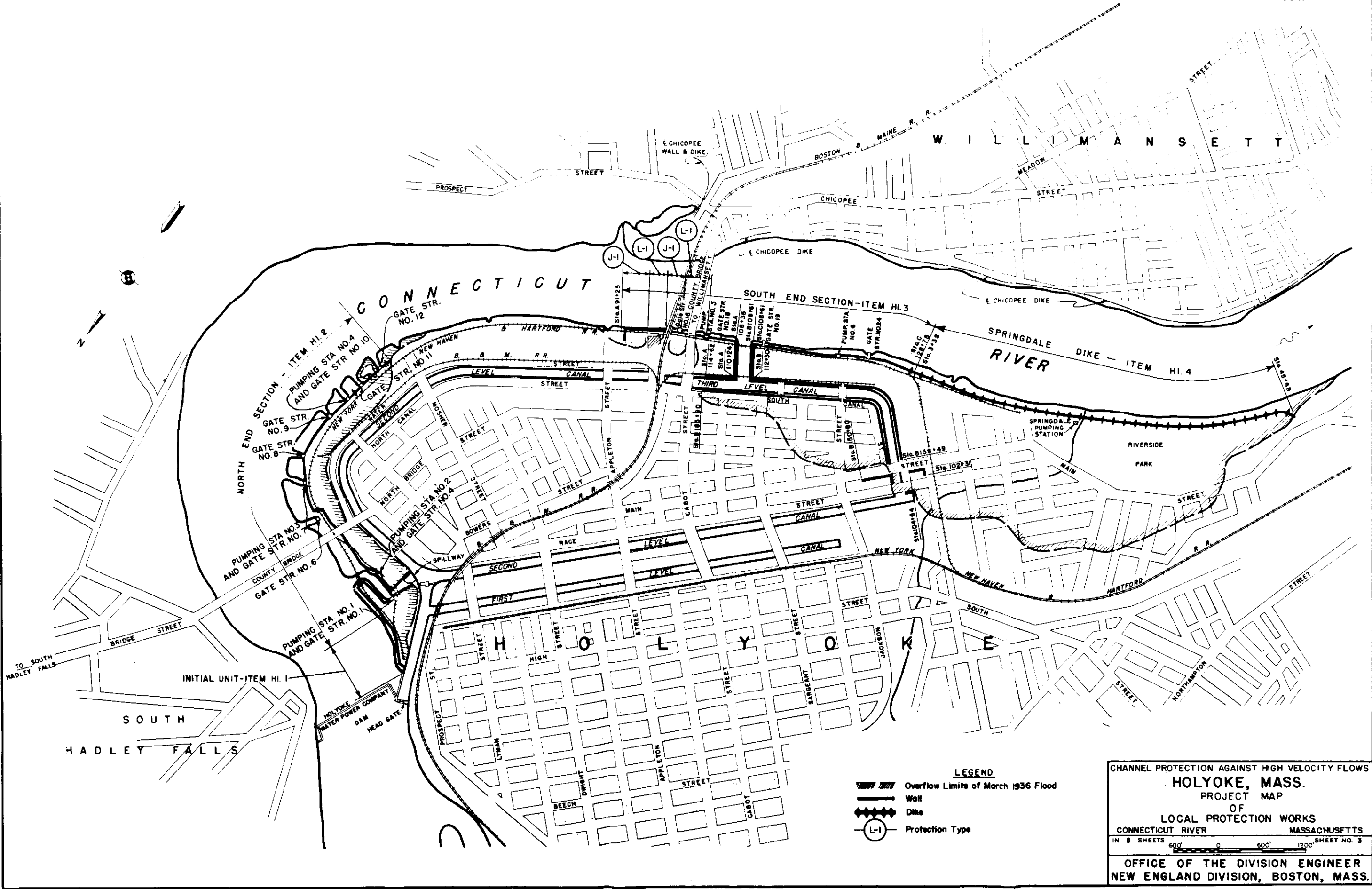
Inclosures:
6 Plates
14 Figures

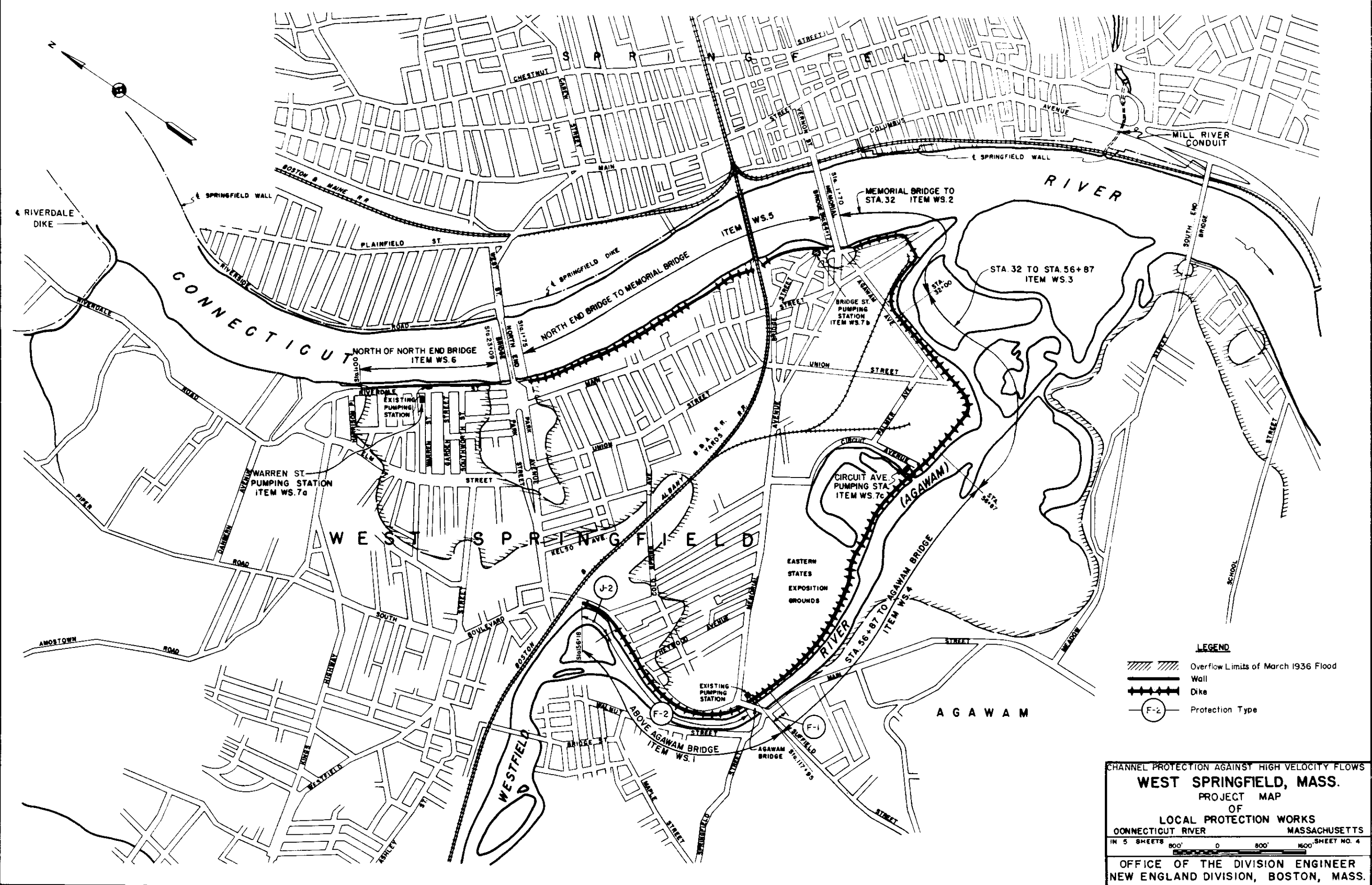


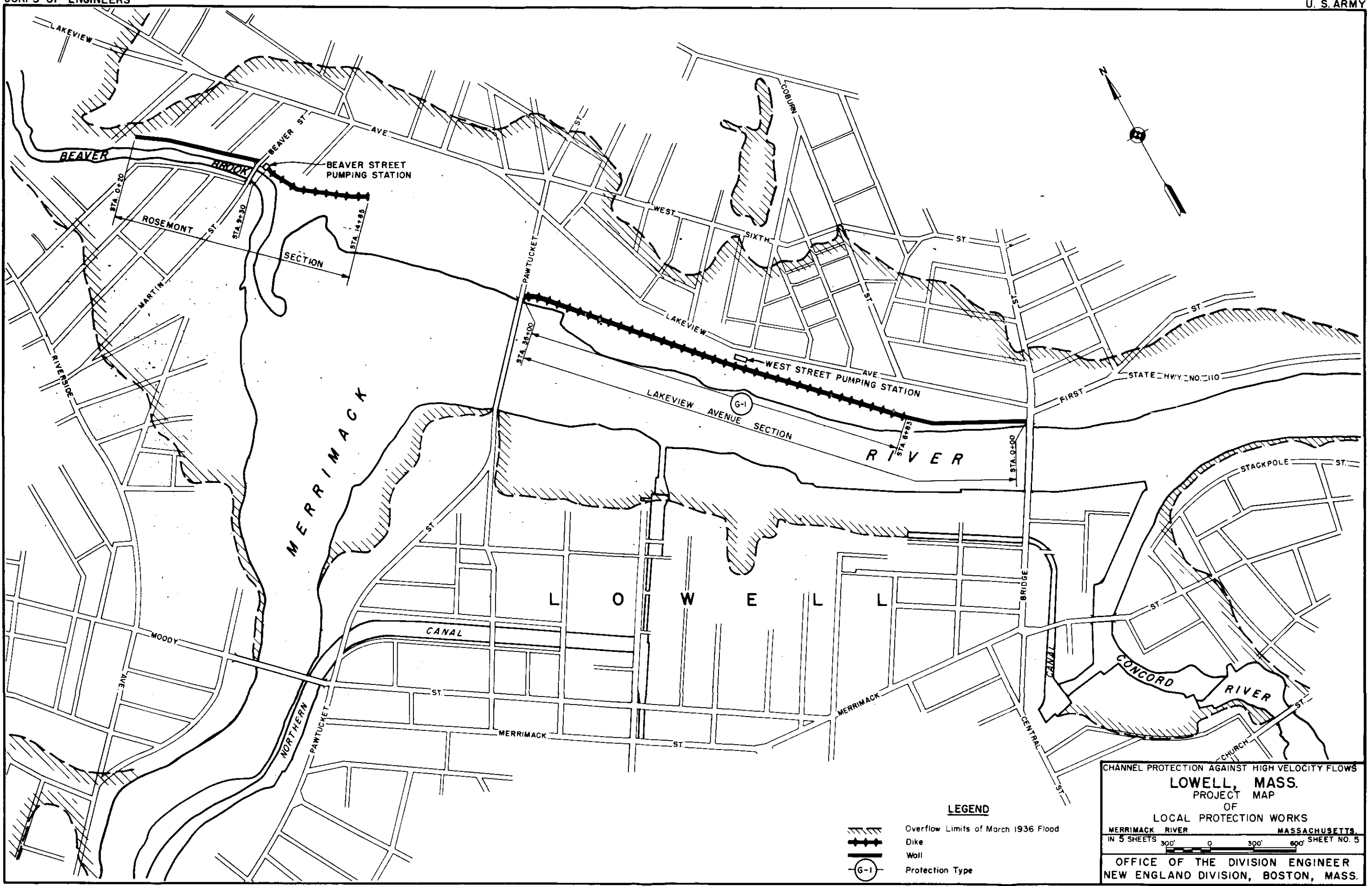
LOCATION MAP
SCALE IN MILES
OFFICE OF THE DIVISION ENGINEER
NEW ENGLAND DIVISION, BOSTON, MASS.

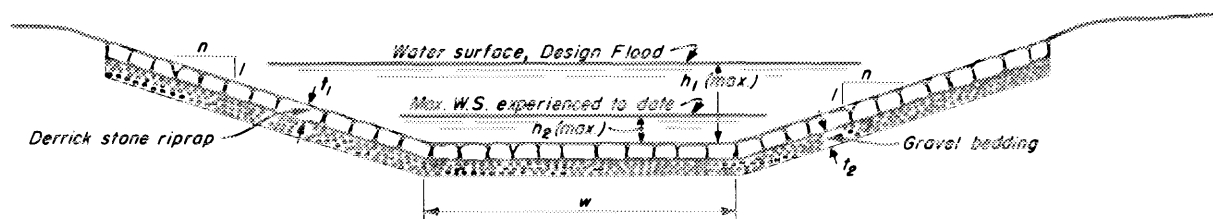




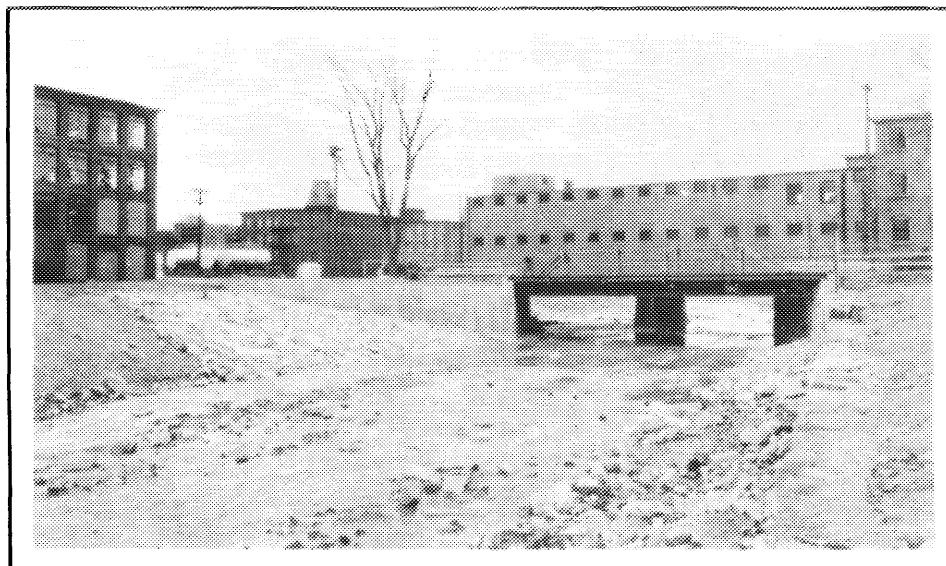








PROTECTION TYPE	PROJECT	YEAR COMPLETED	LOCATION		n	t ₁ in.	t ₂ in.	w ft.	h ₁ ft.	h ₂ ft.	MAXIMUM VELOCITIES- ft./sec.	
			From Sta.	To Sta.							Design	Experienced
A-1	Fitchburg	1938	124+60	125+10	1.5	18	0	100	9.6	7.0	7-10	7-10
A-1	Fitchburg	1938	177+55	178+30	1.5	18	0	75	8.9	11.8	9-12	9-12
A-2	Fitchburg	1938	223+60	224+20	3.0	18	0	78	8.5	7.3	12-14	12-14

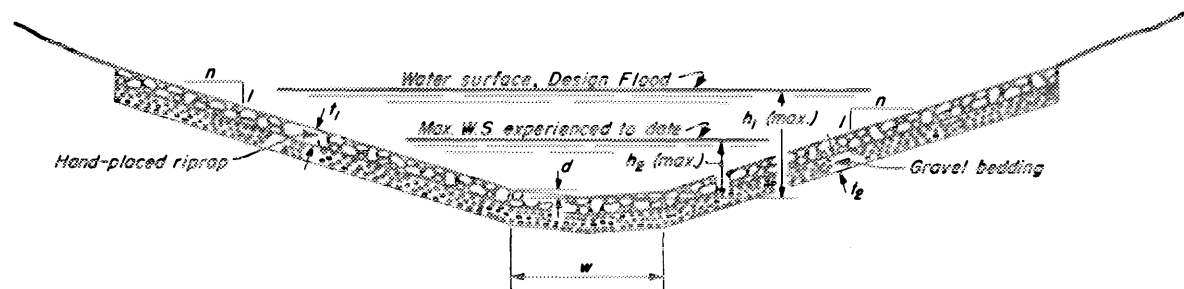


FITCHBURG CHANNEL IMPROVEMENT

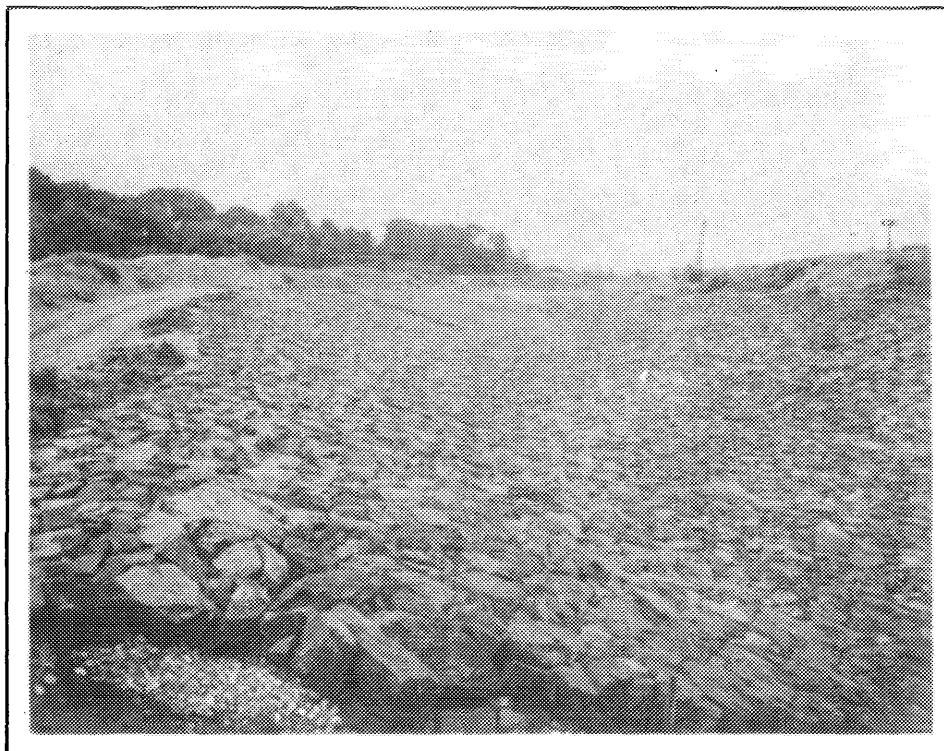
CHANNEL PROTECTION AGAINST HIGH VELOCITY FLOWS

TYPE "A" PROTECTION

OFFICE OF THE DIVISION ENGINEER
NEW ENGLAND DIVISION, BOSTON, MASS.



PROTECTION TYPE	PROJECT	YEAR COMPLETED	LOCATION		n	t ₁ in.	t ₂ in.	w ft.	d ft.	h ₁ ft.	h ₂ ft.	MAX. VELOCITIES - ft./sec.	
			From Sta.	To Sta.								Design	Experienced
B-1	Fitchburg	1938	71+00	71+25	1.5	18	0	110	0	9.7	8.7	7-8	7-8
B-2	Fitchburg	1938	37+80	38+80	2.0	18	0	85	0	9.5	9.7	8-10	8-10
B-2	Fitchburg	1938	238+00	238+70	2.0	18	0	66	0	8.0	6.3	13-18	13-18
B-3	Northampton	1940	1+50	28+07	3.0	12	6	35	1.0	16.2	7.6	11-13	6-8
B-3	Fitchburg	1938	47+60	47+75	3.0	18	0	80	0	9.5	9.4	12-16	12-16
B-3	Fitchburg	1938	48+65	48+75	3.0	18	0	80	0	6.8	5.6	12-16	12-16

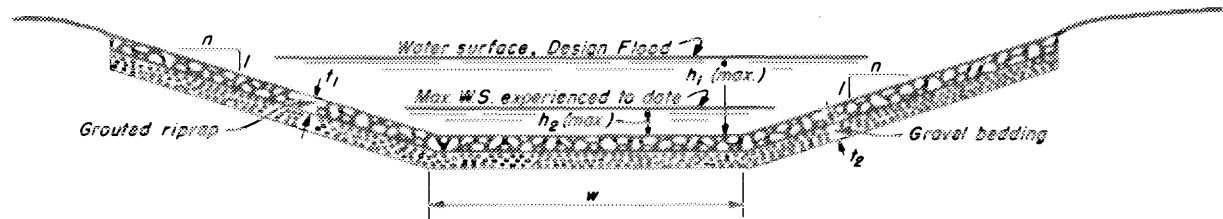


NORTHAMPTON DIVERSION CANAL

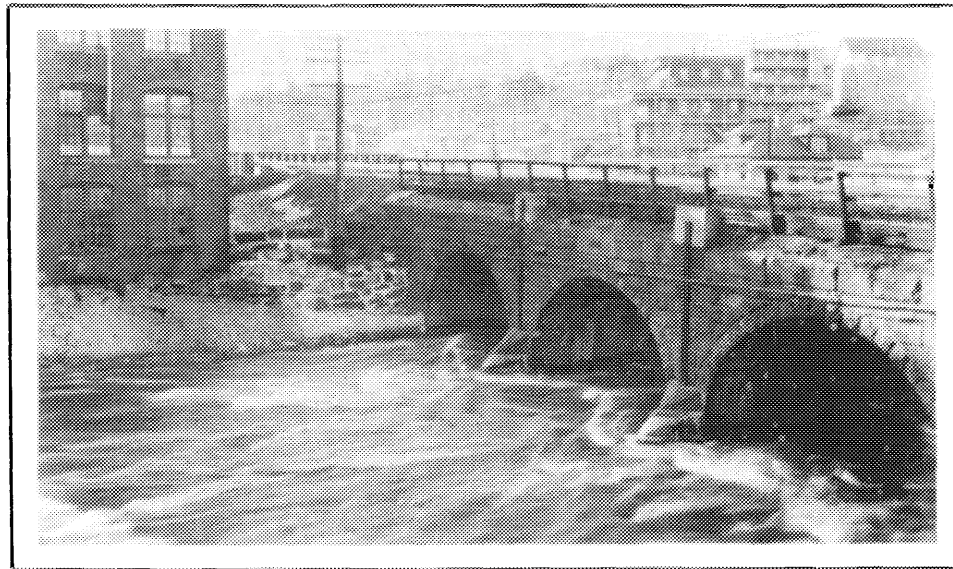
CHANNEL PROTECTION AGAINST HIGH VELOCITY FLOWS

TYPE "B" PROTECTION

OFFICE OF THE DIVISION ENGINEER
NEW ENGLAND DIVISION, BOSTON, MASS.



PROTECTION TYPE	PROJECT	YEAR COMPLETED	LOCATION		n	t ₁ in.	t ₂ in.	w ft.	h ₁ ft.	h ₂ ft.	MAXIMUM VELOCITIES - ft./sec.	
			From Sta.	To Sta.							Design	Experienced
C-1	Fitchburg	1938	71+25	71+79	1.5	18	0	110	9.8	8.8	7-8	7-8
C-2	Fitchburg	1938	239+70	240+25	2.0	18	0	66	8.0	6.8	10-14	10-14
C-3	Fitchburg	1938	47+75	48+65	3.0	18	0	80	9.5	9.4	12-16	12-16
C-3	Fitchburg	1938	224+20	225+10	3.0	18	0	60	10.4	8.1	13-17	13-17

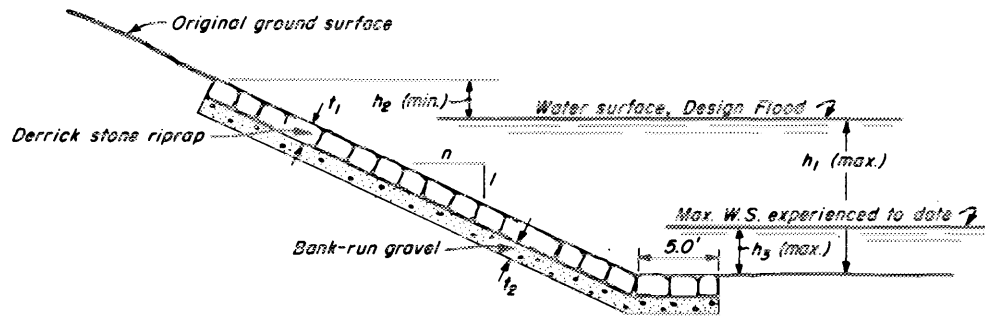


FITCHBURG CHANNEL IMPROVEMENT

CHANNEL PROTECTION AGAINST HIGH VELOCITY FLOWS

TYPE "C" PROTECTION

OFFICE OF THE DIVISION ENGINEER
NEW ENGLAND DIVISION, BOSTON, MASS.



PROTECTION TYPE	PROJECT	YEAR COMPLETED	LOCATION		n	t ₁ in.	t ₂ in.	h ₁ ft.	h ₂ ft.	h ₃ ft.	MAXIMUM VELOCITIES- ft./sec.	
			From Sta.	To Sta.							Design	Experienced
D-1	Fitchburg	1938	137+20	141+30	1.0	24	0	13.5	1.5	12.0	10-14	10-14
D-2	Fitchburg	1938	141+30	142+50	1.5	24	0	12.0	3.0	11.3	10-13	10-13
D-3	Fitchburg	1938	123+30	123+60	2.0	30	0	8.8	4.0	8.0	10-12	10-12

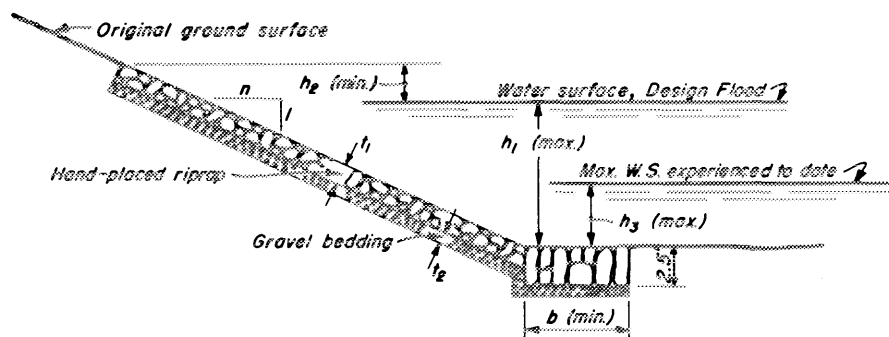


FITCHBURG CHANNEL IMPROVEMENT

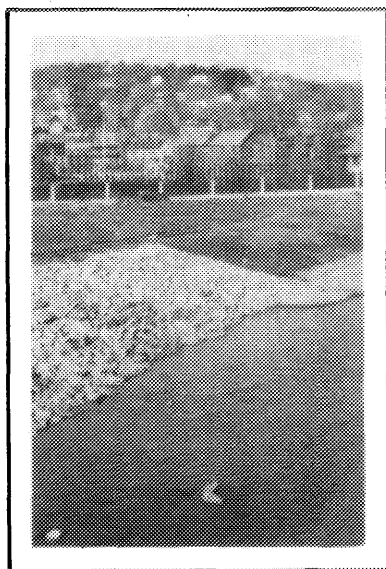
CHANNEL PROTECTION AGAINST HIGH VELOCITY FLOWS

TYPE "D" PROTECTION

OFFICE OF THE DIVISION ENGINEER
NEW ENGLAND DIVISION, BOSTON, MASS.



PROTECTION TYPE	PROJECT	YEAR COMPLETED	LOCATION		n	t ₁ in.	t ₂ in.	b ft.	h ₁ ft.	h ₂ ft.	h ₃ ft.	MAX. VELOCITIES - ft./sec.	
			From Sta.	To Sta.								Design	Experienced
E-1	Fitchburg	1938	150+00	150+80	1.5	18	0	5	10.5	5	10.2	8-10	8-10
E-1	Fitchburg	1938	246+60	247+60	1.5	18	0	5	8.0	5	5.8	12-18	12-18
E-2	Fitchburg	1938	123+60	124+60	2.0	18	0	5	8.8	4	8.0	9-12	9-12
E-2	Fitchburg	1938	150+80	155+70	2.0	18	0	5	10.3	3	10.2	8-10	8-10
E-2	Fitchburg	1938	153+70	155+30	2.0	18	0	5	10.3	3	10.2	8-10	8-10
E-2	Fitchburg	1938	173+50	177+55	2.0	18	0	5	10.7	3	12.4	8-10	8-10
E-2	Fitchburg	1938	190+60	191+90	2.0	18	0	5	13.5	0	9.9	7-10	7-10
E-2	Fitchburg	1938	208+10	210+50	2.0	18	0	5	12.0	0	11.0	6-9	6-9
E-2	Fitchburg	1938	208+10	212+00	2.0	18	0	5	12.0	0	11.0	6-9	6-9
E-2	Fitchburg	1938	214+30	217+20	2.0	18	0	5	9.9	3	8.8	9-11	9-11
E-2	Fitchburg	1938	234+00	236+60	2.0	18	0	5	9.4	0	9.0	9-11	9-11
E-2	Fitchburg	1938	248+40	251+50	2.0	18	0	5	10.2	3	8.2	9-12	9-12
E-3	Fitchburg	1938	48+75	50+00	3.0	18	0	5	6.8	6	5.5	12-16	12-16
E-3	Fitchburg	1938	82+60	85+40	3.0	18	0	5	8.8	4	7.2	10-13	10-13
E-3	Fitchburg	1938	115+90	124+60	3.0	18	0	20	8.4	4	7.2	10-13	10-13
E-3	Fitchburg	1938	122+50	123+30	3.0	18	0	5	8.8	0	8.0	9-12	9-12
E-3	Fitchburg	1938	191+90	193+00	3.0	18	0	5	13.5	0	9.9	5-8	5-8
E-3	Fitchburg	1938	244+00	246+60	3.0	18	0	20	8.4	5	7.1	8-12	8-12



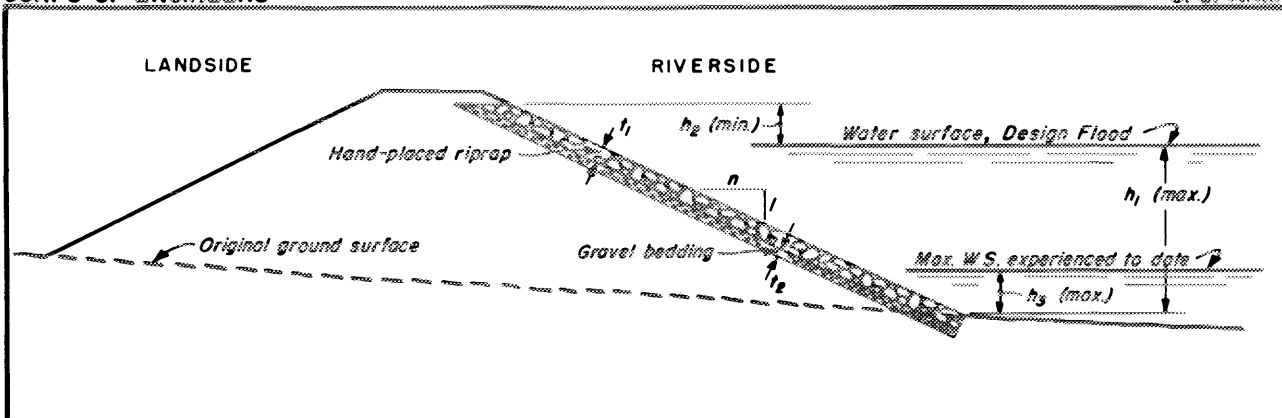
FITCHBURG CHANNEL
IMPROVEMENT

CHANNEL PROTECTION AGAINST HIGH VELOCITY FLOWS

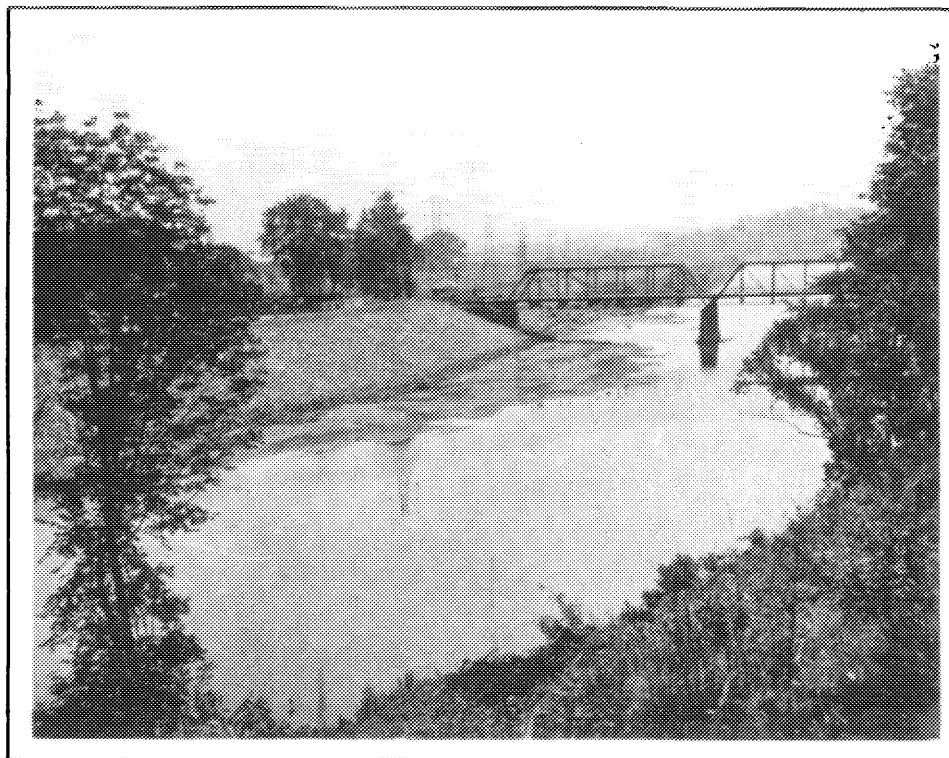
TYPE "E" PROTECTION

OFFICE OF THE DIVISION ENGINEER
NEW ENGLAND DIVISION, BOSTON, MASS.

FIG. 5



PROTECTION TYPE	PROJECT	YEAR COMPLETED	LOCATION		n	t ₁ in	t ₂ in	h ₁ ft	h ₂ ft	h ₃ ft	UNDERLYING MATERIAL	MAX. VELOCITIES - ft./sec.	
			From Sta.	To Sta.								Design	Experienced
F-1	W. Springfield	1938	115+00	117+95	2.0	12	6	18	1	17.5	Impervious	8-10	6-8
F-2	W. Springfield	1939	118+30	150+18	2.5	12	6	23	1	15.0	Impervious	6-9	5-7
F-3	Fitchburg	1938	56+04	56+42	3.0	18	0	10	0	7.1	Random	8-12	8-12
F-3	Fitchburg	1938	56+23	56+60	3.0	18	0	10	0	7.1	Random	8-12	8-12

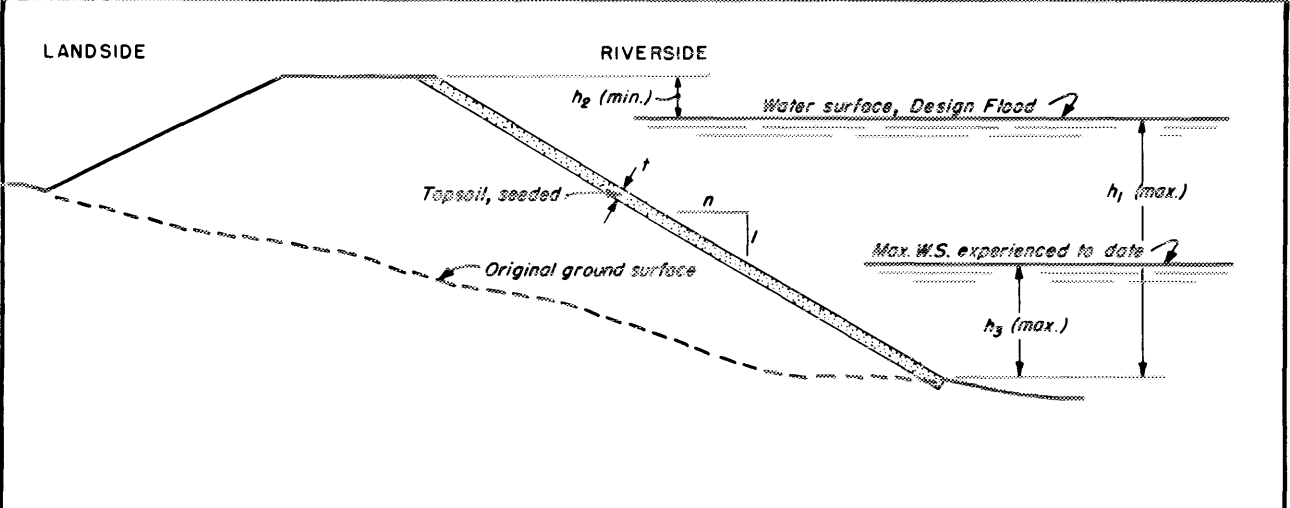


WEST SPRINGFIELD LOCAL PROTECTION

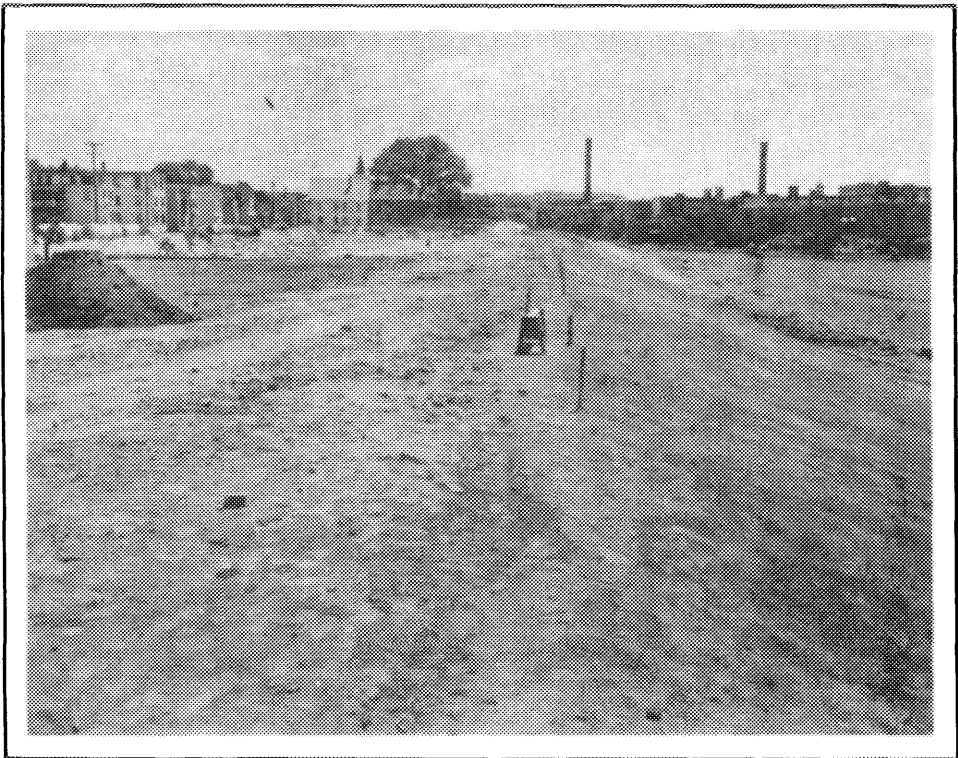
CHANNEL PROTECTION AGAINST HIGH VELOCITY FLOWS

TYPE "F" PROTECTION

OFFICE OF THE DIVISION ENGINEER
NEW ENGLAND DIVISION, BOSTON, MASS.



PROTECTION TYPE	PROJECT	YEAR COMPLETED	LOCATION		n	t in.	h ₁ ft.	h ₂ ft.	h ₃ ft.	MATERIAL UNDER TOPSOIL BLANKET	MAX. VELOCITIES - ft./sec.	
			From Sta.	To Sta.							Design	Experienced
G-1	Lowell	1942	8+83	36+00	3.0	6	22	3	7	Random	13-15	8-10



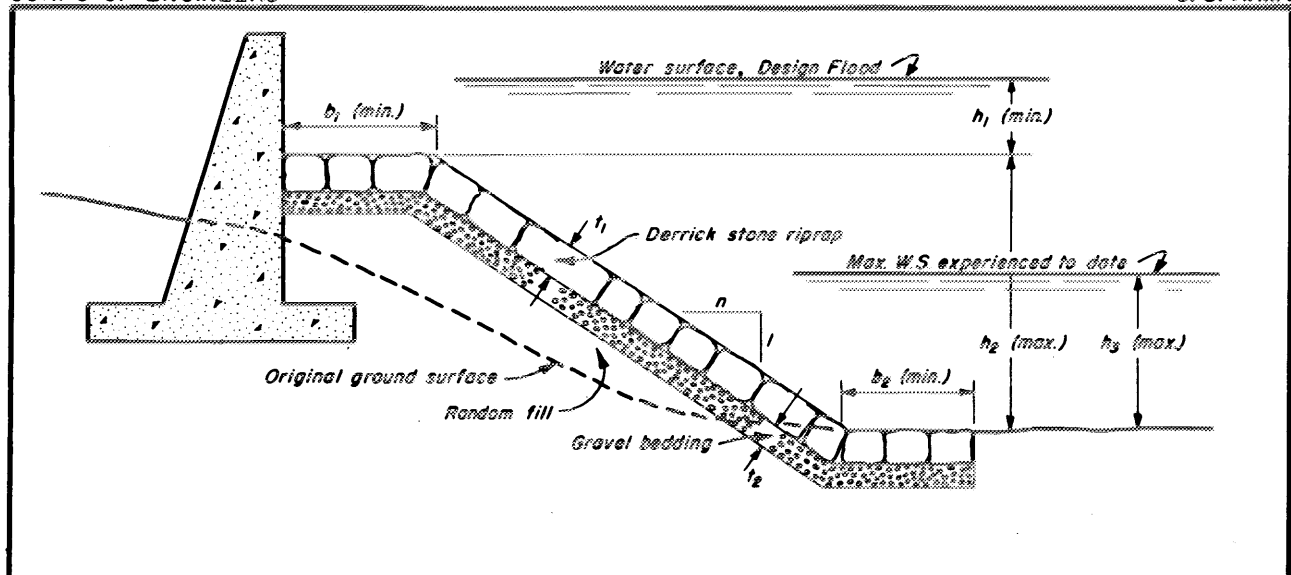
LOWELL LOCAL PROTECTION

CHANNEL PROTECTION AGAINST HIGH VELOCITY FLOWS

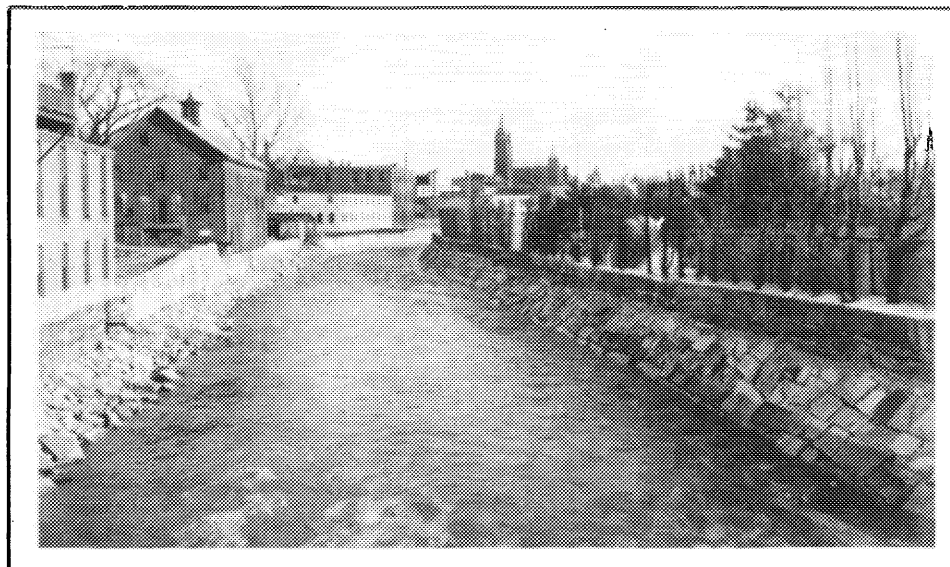
TYPE "G" PROTECTION

OFFICE OF THE DIVISION ENGINEER
NEW ENGLAND DIVISION, BOSTON, MASS.

FIG. 7



PROTECTION TYPE	PROJECT	YEAR COMPLETED	LOCATION		n	t ₁ in.	t ₂ in.	b ₁ ft.	b ₂ ft.	h ₁ ft.	h ₂ ft.	h ₃ ft.	MAX. VELOCITIES- ft./sec.	
			From Sta.	To Sta.									Design	Experienced
H-1	Fitchburg	1938	198+90	208+10	1.0	18	0	0	5	4.0	9.0	11.0	10-12	10-12
H-2	Fitchburg	1938	149+40	153+70	2.0	18	0	0	5	2.5	8.0	10.2	8-10	8-10
H-2	Fitchburg	1938	162+50	167+00	2.0	18	0	0	5	7.0	5.0	10.2	11-13	11-13
H-2	Fitchburg	1938	169+00	170+65	2.0	18	0	0	5	6.0	5.0	12.1	12-16	12-16
H-2	Fitchburg	1938	182+00	184+00	2.0	18	0	0	5	7.0	4.0	9.8	8-10	8-10
H-2	Fitchburg	1938	198+80	206+10	2.0	18	0	0	5	7.0	6.0	10.5	13-15	13-15

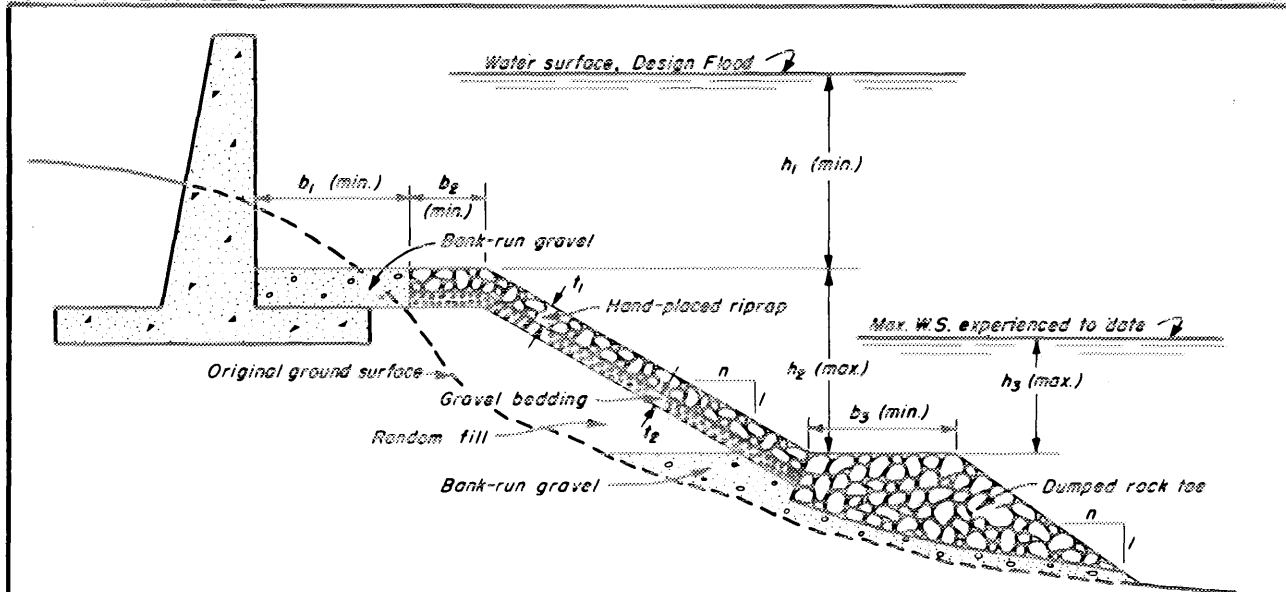


FITCHBURG CHANNEL IMPROVEMENT

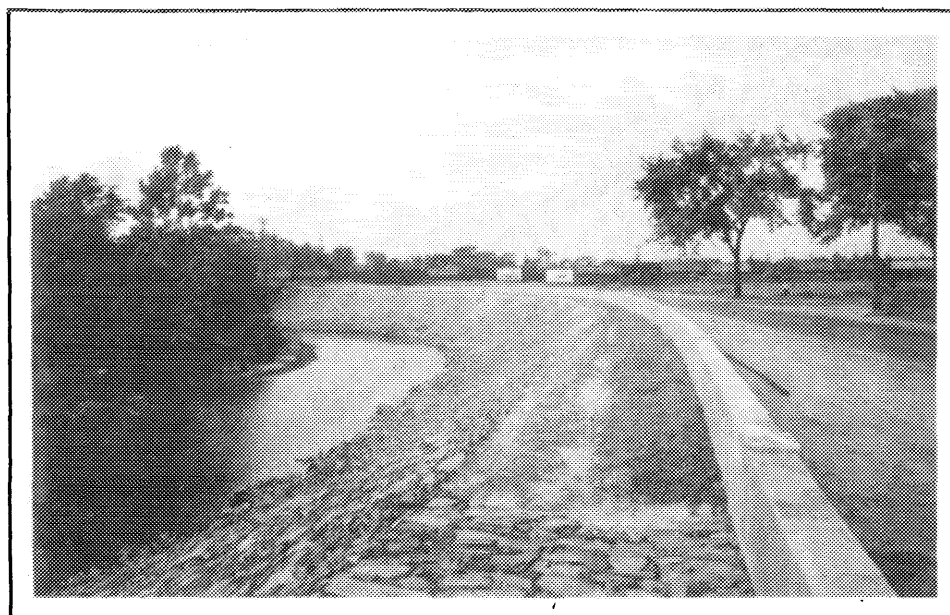
CHANNEL PROTECTION AGAINST HIGH VELOCITY FLOWS

TYPE "H" PROTECTION

OFFICE OF THE DIVISION ENGINEER
NEW ENGLAND DIVISION, BOSTON, MASS.



PROTECTION TYPE	PROJECT	YEAR COMPLETED	LOCATION		n	t_1 in.	t_2 in.	b_1 ft.	b_2 ft.	b_3 ft.	h_1 ft.	h_2 ft.	h_3 ft.	MAX. VELOCITIES - ft./sec.	
			From Sta.	To Sta.										Design	Experienced
J-1	Holyoke	1948	A91+25	A95+70	1.5	12	6	9	2	5.0	8	18	14.5	6-8	5-7
J-1	Holyoke	1948	A97+35	A99+36	1.5	12	6	0	12	5.0	12	15	15.5	7-9	6-8
J-2	W. Springfield	1939	150+18	156+18	2.0	12	6	10	0	5.0	4	22	18.0	6-9	5-7

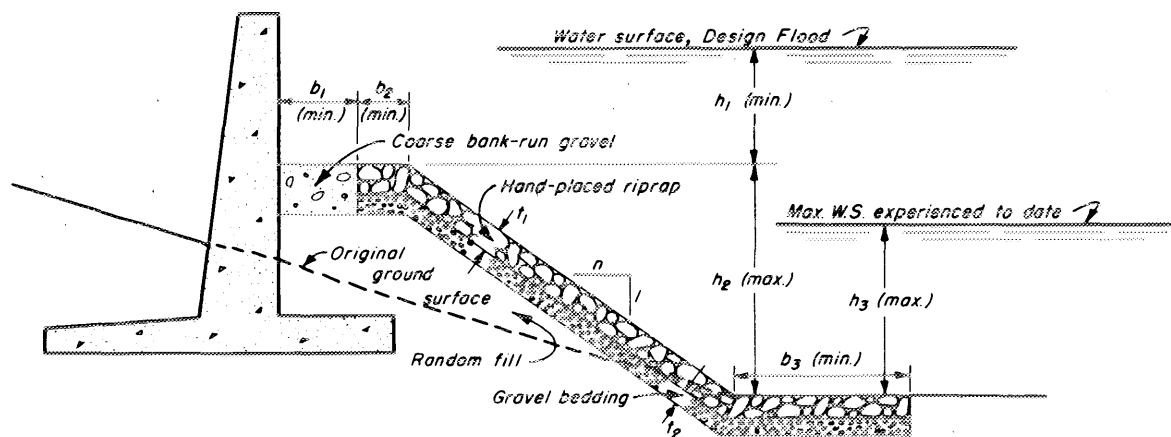


WEST SPRINGFIELD LOCAL PROTECTION

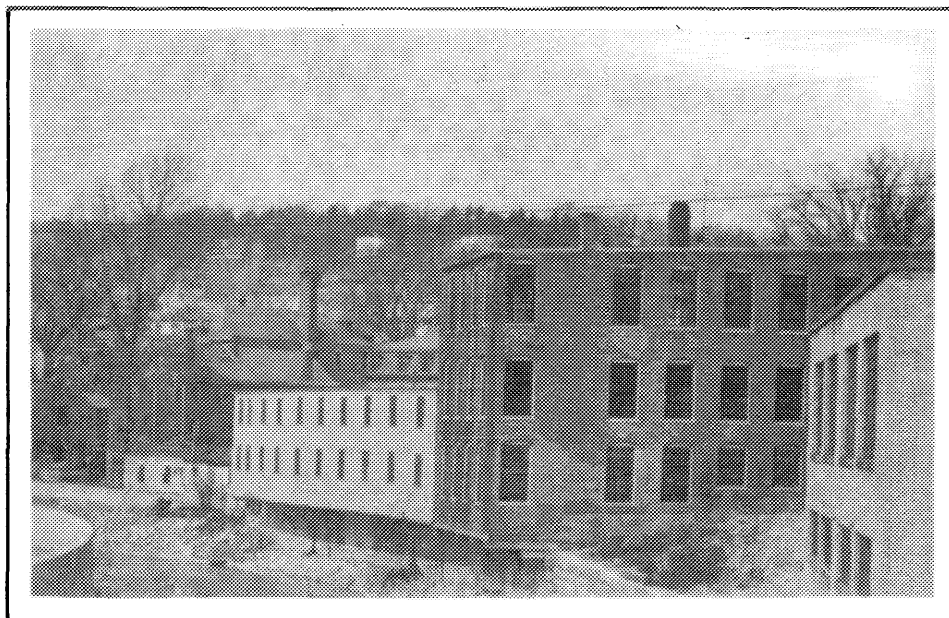
CHANNEL PROTECTION AGAINST HIGH VELOCITY FLOWS

TYPE "J" PROTECTION

OFFICE OF THE DIVISION ENGINEER
NEW ENGLAND DIVISION, BOSTON, MASS.



PROTECTION TYPE	PROJECT	YEAR COMPLETED	LOCATION		n	t ₁ in.	t ₂ in.	b ₁ ft.	b ₂ ft.	b ₃ ft.	h ₁ ft.	h ₂ ft.	h ₃ ft.	MAX. VELOCITIES - ft./sec.	
			From Sta.	To Sta.										Design	Experienced
K - I	Fitchburg	1938	197+70	198+80	2.0	18	0	0	0	5	8	5	10.5	13-15	13-15

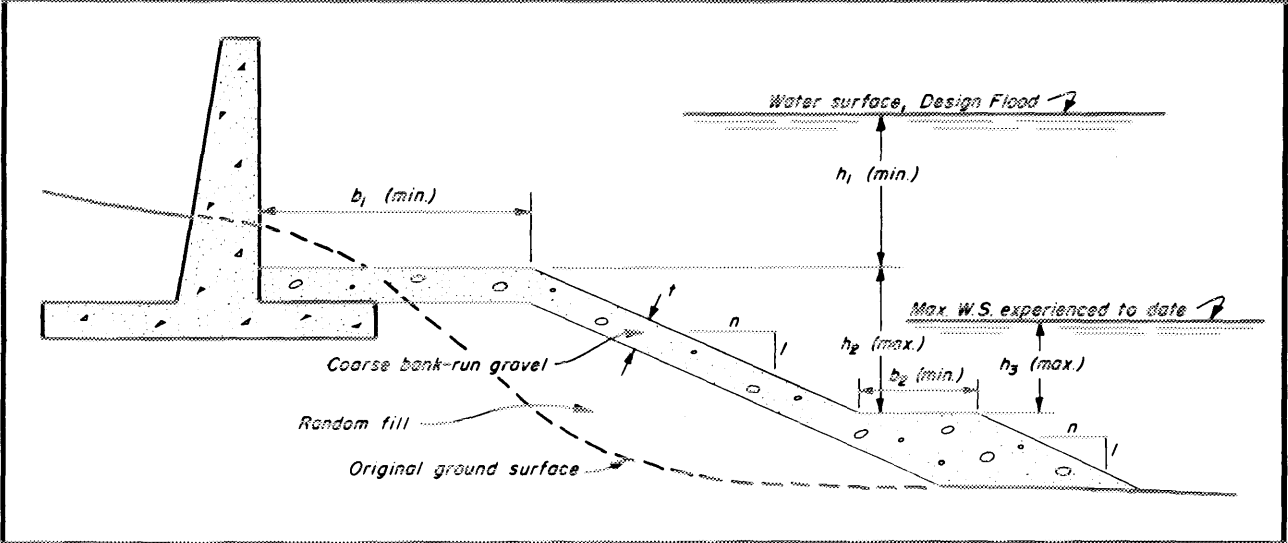


FITCHBURG CHANNEL IMPROVEMENT

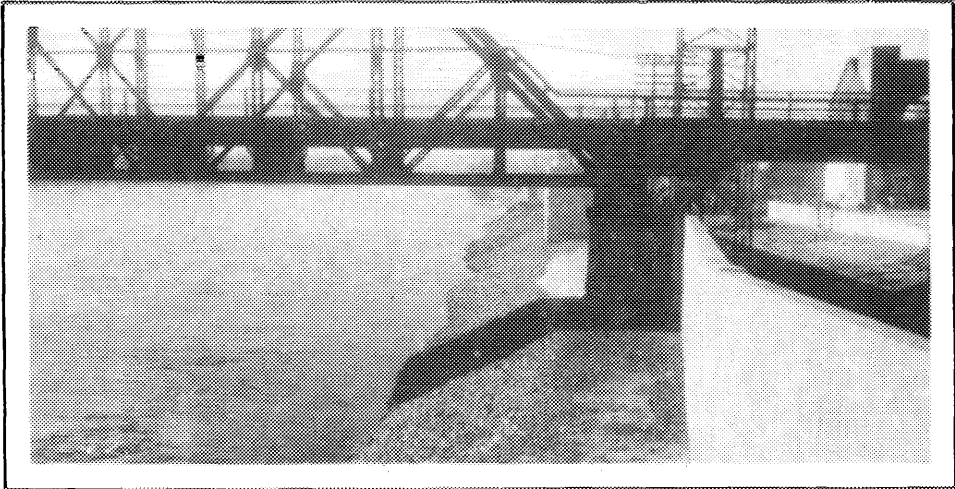
CHANNEL PROTECTION AGAINST HIGH VELOCITY FLOWS

TYPE "K" PROTECTION

OFFICE OF THE DIVISION ENGINEER
NEW ENGLAND DIVISION, BOSTON, MASS.



PROTECTION TYPE	PROJECT	YEAR COMPLETED	LOCATION		n	l in	b ₁ ft.	b ₂ ft.	h ₁ ft.	h ₂ ft.	h ₃ ft.	MAX. VELOCITIES- ft./sec.	
			From Sta.	To Sta.								Design	Experienced
L - I	Holyoke	1948	A95+70	A97+35	2.0	18	19.5	5.0	15	11	14.5	6 - 8	5 - 7
L - I	Holyoke	1948	A99+35	A100+82	2.0	18	14.0	5.0	10	16	14.5	6 - 8	5 - 7



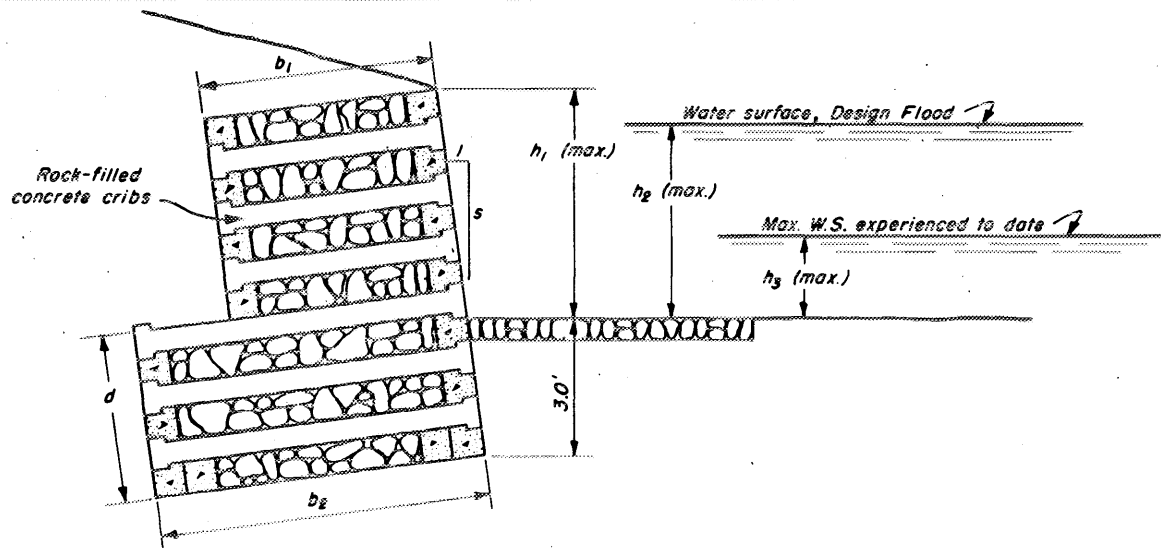
HOLYOKE LOCAL PROTECTION

CHANNEL PROTECTION AGAINST HIGH VELOCITY FLOWS

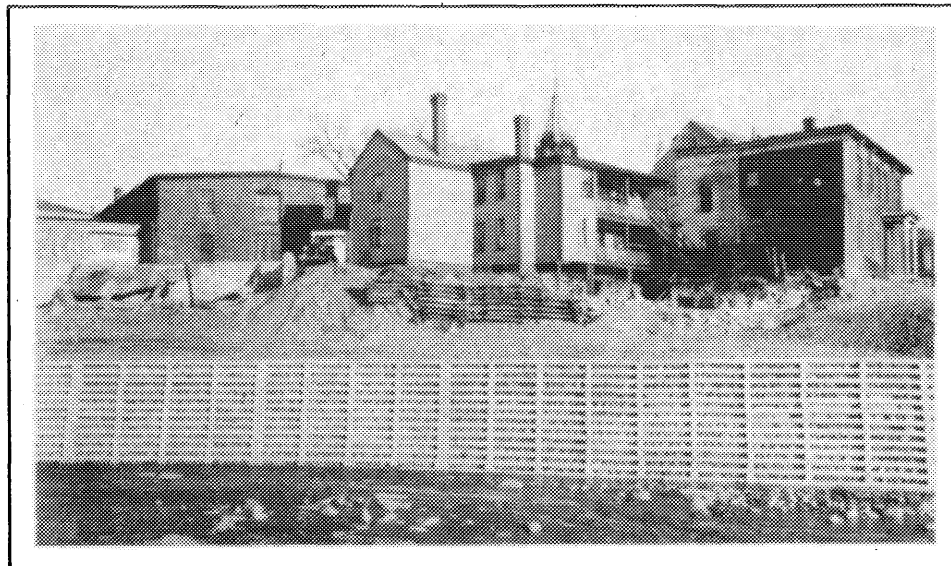
TYPE "L" PROTECTION

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FIG. 11



PROTECTION TYPE	PROJECT	YEAR COMPLETED	LOCATION		s	b ₁ ft.	b ₂ ft.	d ft.	h ₁ ft.	h ₂ ft.	h ₃ ft.	MAX. VELOCITIES- ft./sec.	
			From Sta.	To Sta.								Design	Experienced
M-1	Fitchburg	1938	147+45	149+33	3.0	6.0	6.0	0	15.0	11.3	10.9	8-10	8-10
M-2	Fitchburg	1938	170+90	173+50	4.0	8.0	8.0	0	14.0	11.3	12.5	9-11	9-11
M-3	Fitchburg	1938	155+70	157+00	6.0	6.0	6.0	0	6.0	8.2	8.0	14-16	14-16
M-3	Fitchburg	1938	158+00	159+30	6.0	6.0	8.0	4.3	10.3	11.4	9.8	11-13	11-13
M-3	Fitchburg	1938	193+90	195+50	6.0	6.0	8.0	4.3	13.0	11.9	10.2	8-10	8-10
M-3	Fitchburg	1938	236+60	238+00	6.0	6.0	8.0	4.3	13.0	8.6	7.8	13-15	13-15

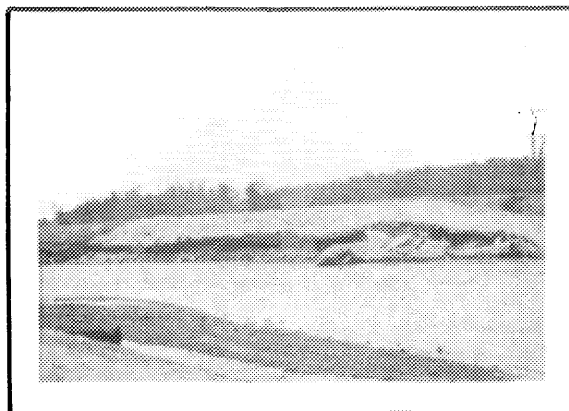


FITCHBURG CHANNEL IMPROVEMENT

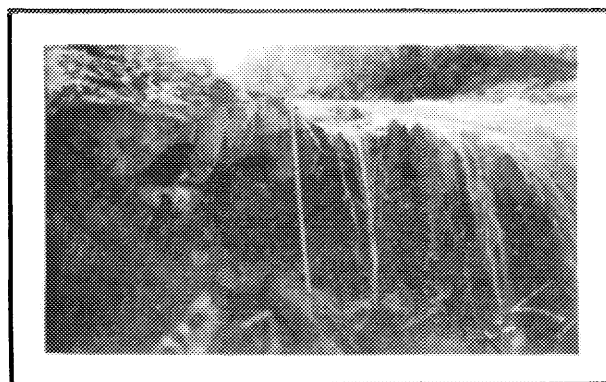
CHANNEL PROTECTION AGAINST HIGH VELOCITY FLOWS

TYPE "M" PROTECTION

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Destruction of Sewer Syphon Dam
Fitchburg, Mass. - Flood of Sept. 1938



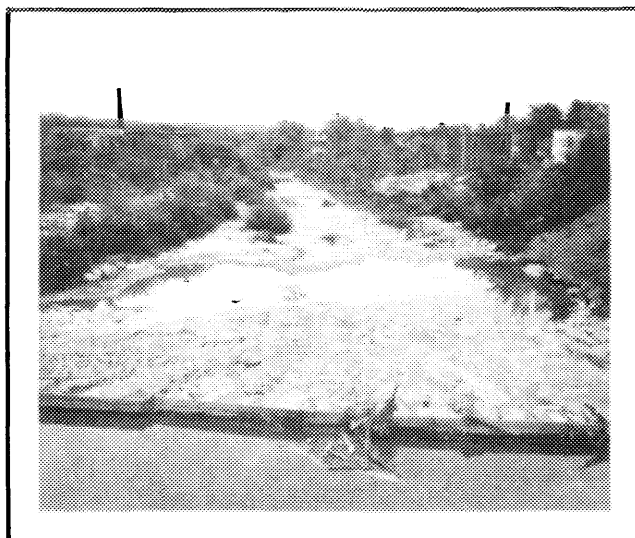
Undercutting of Relocated Canal
Fitchburg, Mass.

CHANNEL PROTECTION AGAINST HIGH VELOCITY FLOWS

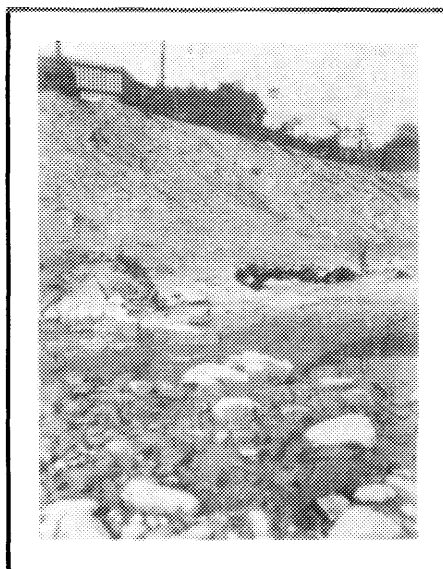
FAILURES OF
TYPE "C" PROTECTION

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FIG. 13



Erosion of Right Bank below Bemis Dam
Fitchburg, Mass.



Close-up of Right Bank below Bemis Dam
Fitchburg, Mass.

CHANNEL PROTECTION AGAINST HIGH VELOCITY FLOWS

**FAILURES OF
TYPE "C" PROTECTION**

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NEW ENGLAND DIVISION, BOSTON, MASS.